Data-Driven Boundary Correction and Optimization of a Nearshore Wave and Hydrodynamic Model to Enable Rapid Environmental Assessment

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Award Number: N00014 N00014-09-1-0503
http://ceprofs.civil.tamu.edu/jkaihatu/research/proj.html

LONG-TERM GOALS

The present project is part of a comprehensive effort by the PI, his students, and collaborators at the Naval Research Laboratory to increase the robustness and viability of the Delft3D model suite as an operational forecasting tool, and aid its continued transition to Navy forecasting centers. Prior projects have focused on determining the model's response to characteristics and sample sizes of bathymetric information. The present project focuses on determining the effect of boundary errors on model response, and the development of methods to ameliorate these issues. These boundary errors arise when the numerical grid for the forcing condition (wave model) is is insufficiently extended in the lateral (longshore) direction relative to the numerical grid for the current (flow model).

OBJECTIVES

The primary objective of this work is to investigate the effect of boundary forcing errors on the model response. This has a direct impact on the use of Neumann lateral boundary conditions, since these errors arise from insufficient extension of the WAVE (SWAN) grid beyond the lateral boundaries of the FLOW grid. There is a balance between accuracy and computational efficiency that must be struck; the computational bottleneck in the Delft3D system is SWAN, the wave model, and the run time increases with lateral extent of the WAVE grid. While point-by-point comparisons between model and data for various WAVE grid extensions can offer a view of the dependence of accuracy on grid extension, it does not yield any information on the spatial characteristics of the solution; poor data-model comparison could be the result of slight spatial mismatches of highly variable solution fields, or oversmoothed solutions which have little relevance to the physics at hand.

APPROACH

Among the recent enhancements to the utility of the Delft3D model for nearshore process simulation include the implementation of Neumann lateral boundary conditions (Roelvink and Walstra 2004), which allow for flow to enter and leave the lateral boundaries with no artificial circulation. This boundary condition is formulated by reducing the flow equations in the hydrodynamic model to a single dimension, which has the effect of setting conditions on the *gradient* of the velocities rather than

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE **Data-Driven Boundary Correction and Optimization of a Nearshore Wave and Hydrodynamic Model to Enable Rapid Environmental Assessment**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Texas A&M University,Zachry Department of Civil Engineering,3136 TAMU,College Station,TX,77843-3136**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

on the velocities themselves. For wave-induced flow, however, one consequence is the need to have a wave-model grid that is significantly wider than the hydrodynamic model grid; this is done in order to keep irregularities in the forcing away from the boundaries of the hydrodynamic model. However, SWAN, the wave model for Delft3D, requires significant iterative steps, and as such is a computational chokepoint for forecast turnaround. One of our primary goals in this project is to evaluate the errors as a function of the lateral grid extent.

One aspect of the error analysis we are investigating is the effect of reducing the lateral extent of the wave model domain. We first analyze the effect that small deviations from complete satisfaction of the Neumann boundary condition have on the hydrodynamic predictions. This is done first by perturbing the equations describing the lateral boundary condition by a small error, and examining the growth or decay of that error, analogous to Chen and Svendsen (2003) for the case of errors in the flow velocity at the boundary. We then indirectly impose a deviation from the satisfaction of the zero Neumann boundary condition by incrementally shortening the lateral extent of the wave model grid, and determining the effect on the model results. The analysis of the error will require some method of looking at the multi-dimensional tendencies of the error and some estimation of the scales most vulnerable to error, rather than just the deviation between model and data. To this extent, we use spatio-temporal analysis methods such as Empirical Orthogonal Function (EOF) analysis to determine the overall scales of motion in the flow field and the extent of the variation of their response to the errors.

Statistical information on the errors along the boundaries will be useful for another aspect of the project, which involves the development of methods to correct these forcing errors using data taken within. A Kalman-filter-style (Van Dongeren 2008) assimilation and correction system will be investigated for use herein to perform this boundary correction; later implementation of simplified versions of this model will likely lead to the use of adjoint methods for this.

Mr. Boyang Jiang (B.S. Hydropower Engineering, Hohai University, Nanjing, PRC) was the graduate assistant in primary charge of this work. He was the second in an envisioned line of students working on various aspects of the Delft3D model while pursuing graduate degrees at Texas A&M University, and is performing the majority of the evaluative work. Mr. Jiang defended his M.S. thesis in 2010, and has left to work in industry. We have engaged a new Ph.D. student, Ms. Samira Ardani (B.S. and M.S., Department of Civil Engineering, K.N. Toosi University of Technology, Tehran, Iran), to continue the work and implement Monte-Carlo-based evaluation of model robustness along the boundaries of the FLOW model.

WORK COMPLETED

The work this year has been in some transition. We are writing up the work on the EOF method we described in last year's report for publication. Ms. Ardani has become proficient with the Delft3D model and has begun re-running some of Mr. Jiang's cases in order to improve her knowledge of the model and to build up experience with it.

To evaluate the spatial scales affected by the errors of insufficient A/B ratio, we calculated the wavenumber spectrum of the different components of velocity in the EOF modes and compared them across A/B ratios. We also prepared a publication on the optimized bathymetric survey method using genetic algorithms, based on work done under a precursor of this project.

RESULTS

Figure 1 shows the Mode 8 cross-shore velocity EOF for a one-month Delft3D run over the NCEX bathymetry, done for A/B=50% and 25%. While Mode 1 (not shown) shows virtually no difference between A/B ratios, Mode 8 shows substantial differences in the spatial structure. This is apparent in the wavenumber spectra shown in Figure 1C and 1F. The case of A/B=50% retains more structure in the longshore scales than A/B=25%, where the energy is spread over more wavenumbers.

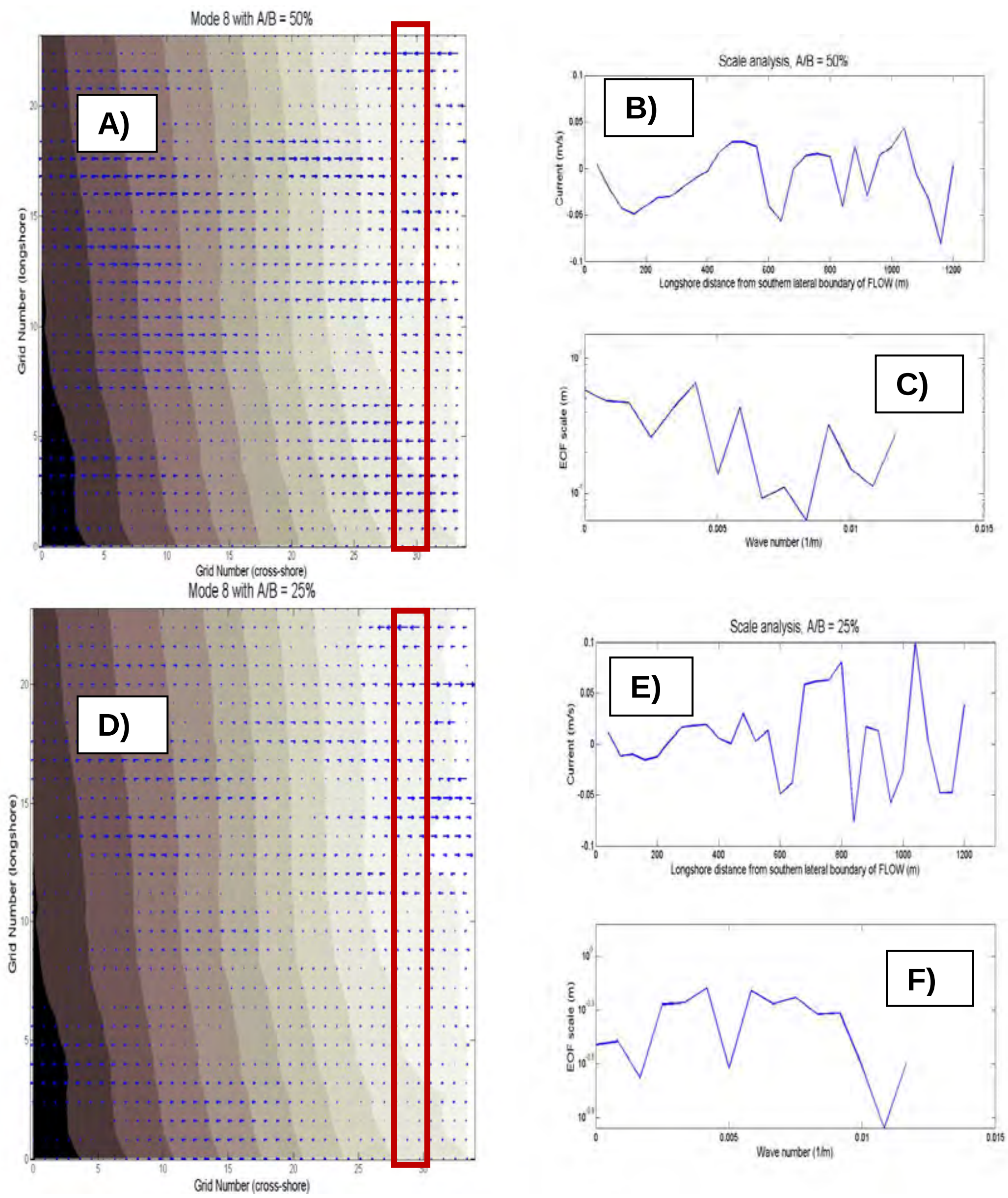

Figure 1. Scale analysis of EOF modes calculated from one month of NCEX runs of Delft3D: Mode 8. A) Crossshore modal velocities over bathymetric contours for A/B =50%. B) Scaled cross-shore velocities in red box. C) EOF wavenumber spectrum for Mode 8. D), E) and F) – same as for A), B), and C) except for A/B=25%.

IMPACT/APPLICATIONS

Our analysis methodology can be used to analyze optimum setups for a given area of interest, for which one may anticipate the need for forecasts for a significant span of time. Since the shorter WAVE grids lead to both more error and more expedient calculation, a balance may be sought between accuracy and speed of the forecast. Furthermore, it may be possible to perform EOFs on forcing errors, which can then be used to elicidate process sensitivity to error and, ultimately, to correct boundary information.

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